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CRITERIA FOR COMPACT SHORE TRANSMITTING ANTENNAS
BY SYSTEMS EXPLORATIONS INC

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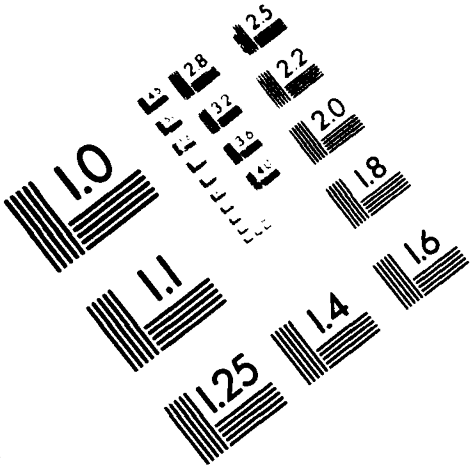

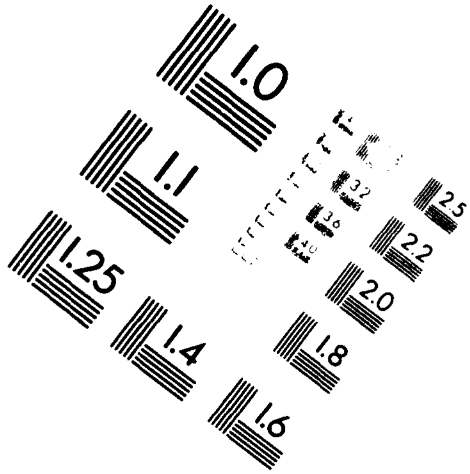

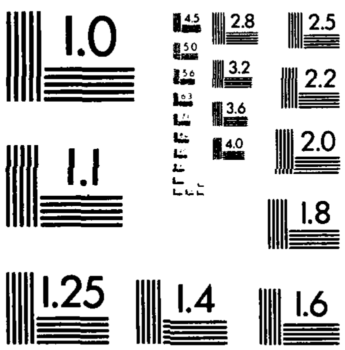

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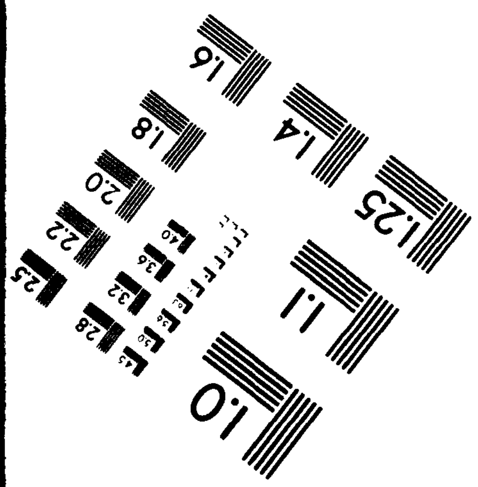

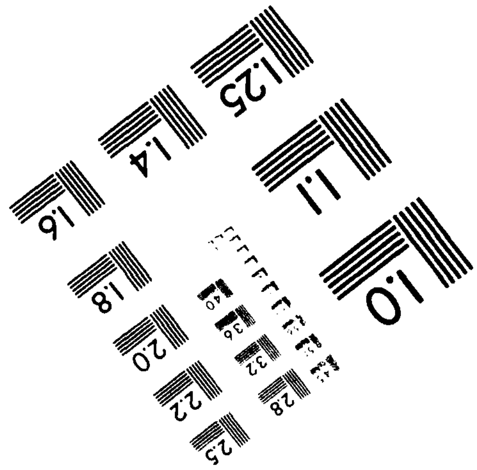

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CRITERIA FOR COMPACT SHORE TRANSMITTING ANTENNAS

Systems Exploration, Inc.

Naval Ocean Systems Center San Diego, California 92152-5000

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Systems-related criteria are used in evaluating several candidate approaches aimed at the reduction of land area needed to support a given HF transmitting communications requirement. The various design alternatives are (a) broadband antenna with tunable multicoupler, (b) broadband 6–30 MHz antenna with 2–6 MHz base tuner, (c) 2–4 and 4–8 MHz Moderate-Q antennas, and (d) 2–6 MHz tuned whip antenna. The tunable multicoupler is best suited for directional or high-angle antennas. The tuned antennas are best suited for use at new station.

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EXECUTIVE SUMMARY

This report presents some of the system-related criteria for use in evaluating various design alternatives for reducing shore antenna area requirements. The primary design alternatives are: (a) broadband antennas with tunable multicoupler; (b) broadband 6-30 MHz antenna with 2-6 MHz base tuner; (c) 2-4 and 4-8 MHz Moderate-Q antennas; and (d) 2-6 MHz tuned-whip antenna. Estimates are made as to the relative performance to be expected from the alternatives and the design problems that may be encountered. Tentative estimates are included for expected development and implementation costs, for development time, and for development risk.

The four main alternatives have about the same potential for decreasing land area requirements: a reduction of 4 to 8 times as compared to use of all broadband antennas. The tunable multicoupler is best suited for use on directional or high-angle antennas. The tuned antennas are best suited for use at new stations. Changes to existing stations may be obtained at lowest cost through the application of high-pass/low-pass (HP/LP) filters. No development is required for these off-the-shelf items.

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TITLE

TABLES

CRITERIA FOR

COMPACT SHORE TRANSMITTING ANTENNAS

1.0 INTRODUCTION

Development of technical approaches and detailed requirements for compact shore transmitting antennas is underway at the Naval Ocean Systems Center (NOSC). Systems Exploration, Inc. (SEI) assisted in outlining some candidate approaches as reported in ref. 1. Additional work at SEI resulted in more detailed requirements for three specific approaches chosen by NOSC for development. These results are reported in references 2, 3 and 4.

All of the candidate approaches are aimed at the reduction of land area needed to support a given communications requirement. This takes the form of smaller, tunable antennas or multicouplers to allow the use of several transmitters on a common broadband antenna. At the present time the plans are for development of 4 tunable antennas and a set of tunable multicouplers to cover the 2-30 MHz frequency range. References 2, 3 and 4 contain essential performance requirements for the multicouplers and for two of the tunable antennas.

This report presents some of the systems-related considerations regarding comparative performance of the several approaches. This includes such factors as: (a) efficiency; (b) required area; (c) stability; (d) tuning simplicity; (e) technical risks; (f) cost; (g) flexibility; and (h) estimated development time.

2.0 APPROACH

This report uses the results of the previous SEI reports (references 1-4) as a base for further comparison of the candidate approaches. Reference 1 and this report use the term "compact antenna" as a general term for an approach that reduces land area requirements. The various types are: (a) tuned-whip; (b) Moderate-Q; (c) inverted cone with base tuner; and (d) broadband antenna with multicoupler. Reference 1 treated these approaches. This report adds another type specifically called "compact antenna" because it is much smaller than the others. It is intended for special applications, such as rooftop locations, and for situations that can tolerate lower efficiency. It is treated here as a separate requirement, but some general comparisons are made to the other types. The other types are referred to here by the above descriptive titles.

The more detailed performance requirements of each type as reported in references 2, 3 and 4 provide additional information on design difficulties that may be encountered, possible impact on development and production cost, operability factors, and expected performance limits. This information is used to develop more detailed comparison of their relative merits and to derive performance criteria.

The results of ref.1 included some consideration of a power requirement of 40 kW. This power level has since been set at 10 kW PEP, 5 kW average, and all results reported herein are based on that level.

The computations used for developing design and evaluation criteria herein are based on simplified circuit analyses. There is no attempt made to address details of stray parameters, required switch points (to cover a frequency band), specific limits on available tuning components, or tuning control circuitry. Cost estimates are based on extrapolation of limited available data, supplemented by engineering estimates based on complexity of the designs.

An example set of requirements is used to estimate the number of each type of equipment needed to fill the requirements. These requirements are representative of a medium-sized shore transmitting station. The number of equipments needed is then used to derive estimated cost of each for comparison purposes.

3.0 DESIGN CONSIDERATIONS

3.1 REQUIRED LAND AREA

Reference 1 reported results of an analysis to determine the area required to support the various candidate antennas. This analysis was made using the following circuit requirements: (a) 8 circuits for 2-4 MHz; (b) 21 circuits for 4-8 MHz; and (c) 25 circuits for 8-30 MHz. This analysis assumed that only 2 of the 9 variable-frequency circuits would be in the 2-4 MHz band at any one time. The results covered only the multicoupler, Moderate-Q, and broadband without multicoupler situations. The 2-8 MHz tuned whip and the inverted cone with tuner were not included.

This report adds the results for the latter two antennas. Also the assumed requirements are changed somewhat to reflect the possibility that all of the 9 variable-frequency circuits may be in the 2-4 MHz band. This increases the required area because more 2-4 MHz antennas are needed. This change increases the number of circuits to 15 for 2-4 MHz. Table 3-1 shows results of the increased number.

Table 3-1. Antenna Area Summary

	ANTENNA TYPE	REQUIRED AREA-ACRES
1.	Broadband with 4-unit multicoupler	23
2.	Broadband 6-30 MHz with 2-6 MHz base tuner	19
3.	Moderate-Q for 2-4 and 4-8 MHz; broadband for 8-30 MHz	24
4.	Tuned Whip for 2-6 MHz; broadband for 6-30 MHz	26
5.	All broadband w/o multicoupler	86 to 172

Note 1: Assumed number of circuits is as follows: 2-4 MHz - 15 (9 variable and 6 fixed); 4-8 MHz - 21 (9 variable and 12 fixed); and 8-30 MHz - 25 (9 variable and 16 fixed). The 9 variables can use one antenna each if the antenna covers 2-30 MHz.

Note 2: Area for broadband w/o multicoupler depends on the frequency ranges of the 43 antennas. The smaller number uses the fewest possible number of lower-frequency antennas.

Note 3: Buffer zone and ground system not included.

The required area for each of the three tunable options is comparable, with the inverted cone and 2-6 MHz base tuner having a small advantage. This results from the fact that a single antenna can cover each of the 9 variable-frequency circuits. For the other tunable options, more than one antenna is required for each variable-frequency circuit. The tunable multicoupler option assumes that two broadband antenna types are used - one for 2-6 MHz and one for 6-30 MHz. Each antenna can handle 4 circuits. The option using broadband antennas without multi-couplers needs the greatest area. If all antennas are for 2-30 MHz, 172 acres are needed. The area is reduced to 86 acres if the antennas are divided into 3 ranges - 2-4, 4-8 and 8-30 MHz. The results show the advantage of using fewer low-frequency antennas and of using tunable antennas or multicouplers.

3.2 ESTIMATED SYSTEM COST

It is very difficult to estimate acquisition cost of antennas and equipments until development is further along. However, an attempt is made here to get some comparative cost data in order to assist in evaluating relative merits of the options. These cost estimates are based on extrapolation of available data. Where no data are available, engineering estimates are made based on complexity of the design.

The first requirement is to determine the antennas and equipments necessary to meet the circuit requirements. These requirements are assumed to be as stated in par. 3.1. Table 3-2 presents a summary of these equipments. The tuned whip may cover 2-8 MHz for increased flexibility, but it is shown here as covering 2-6 MHz requirements. This arrangement takes less area than required if the break is made at 8 MHz. The broadband 6-30 MHz antenna is assumed to be an inverted cone.

Table 3-2. Shore Antenna Equipment Summary

ANTENNA TYPE	BROADBAND ANTENNAS	OTHER
1. Broadband with 4-unit multicoupler	2-6 MHz - 6 6-30 MHz - 8	2-6 MHz MC -6 6-15 MHz MC - 8 15-30 MHz MC - 4
2. Broadband 6-30 MHz with 2-6 MHz base tuner	6-30 MHz - 43	2-6 MHz tuner - 21
3. Moderate-Q for 2-4 and 4-8 MHz; broadband for 8-30 MHz	8-30 MHz - 25	2-4 Mhz Mod-Q - 15 4-8 MHz Mod-Q - 21
4. Tuned Whip for 2-6 MHz; broadband for 6-30 MHz	6-30 MHz - 31	2-6 MHz tuned whip - 21
5. Broadband w/o multicoupler	43	NA

Note 1: Assumed number of circuits is as follows: 2-30 MHz variable - 9; 2-4 MHz fixed - 6; 4-8 MHz fixed - 12; 8-30 MHz fixed - 16.

Note 2: Where break occurs at 6 MHz, assumed that half of the 4-8 MHz fixed circuits are below 6 MHz (6 above and 6 below).

Note 3: MC is 4-unit tuned multicoupler.

Note 4: Tuned whip may cover 2-8 MHz but is used primarily 2-6 MHz.

The multicoupler cost estimate is based on estimates made in 1974 for DECO 4-unit shipboard equipments for 1 kW PEP. The estimate was doubled for cost escalation and doubled again for 10 kW PEP operation. The 1974 estimate for cost was increased from 35K per equipment to 140K in 1984 for 10 kW. Some cost data are also available for the AN/SRA-35/36/37 10 kW multicouplers. These data are for a limited production of 5 of each kind, and the time is approximately 1967. Cost of a 4-unit equipment was about 70K. Escalation to 1984 is expected to increase this to over 200K. However, a larger production run may lower the estimate to values near the 140K estimated above. This provides some degree of confidence in the initial estimate.

The lowest cost for broadband antennas was determined as follows: (a) antenna kit for inverted cone antenna was 7.2K in 1976 escalated to 14.4K in 1984; (b) support poles for the antenna - 3.6K; (c) 1000 feet of 3-1/8 inch coaxial cable - 6K; (d) installation cost - 6K; and (e) total cost - 30K. Information from NAVTELCOM indicates that installation cost may be far greater than that estimated here. For that reason additional estimates were added for the broadband antennas for this contingency. These estimates are also included in the table to follow (Table 3-3).

The cost estimates for Moderate-Q, base tuner for the inverted cone, and tuned whip are based on judgement, using the comparative complexity of the various equipments as a guide. It is assumed that cost of the Moderate-Q and the tuned whip is about 30K each. It is further assumed that cost of the tuner for the inverted cone is also about 30K.

These cost estimates were used to develop overall system cost of the various options as applied to the channel requirements set forth in par. 3.1. In all of the cases for tuned antennas it was assumed that broadband antennas without multicoupling are used above 6 or 8 MHz. This assumption has little impact on the required land area. The cost with or without multicoupling is estimated to be about the same for these 6-30 MHz circuits. Operation is simpler when multicouplers are not used.

Table 3-3 shows the estimated system cost of the various options. The cost columns include estimates based on three levels of cost for broadband antennas - 30K, 60K and 100K. If the lowest cost estimate for broadband antennas is correct, the use of broadband antennas without multicouplers results in the lowest overall cost.

Table 3-3. Antenna System Cost Summary

OPTION	ANTENNA TYPE	TOTAL COST - MILLIONS ASSUMP. A	B	C
1.	Broadband with 4-unit multicoupler	2.92	3.34	3.90
2.	Broadband 6-30 MHz with base tuner	1.92	3.21	4.93
3.	Moderate-Q for 2-4 and 4-8 MHz; broadband 8-30 MHz	1.83	2.58	3.58
4.	Tuned whip for 2-6 MHz, broadband for 6-30 MHz	1.56	2.49	3.73
5.	All broadband w/o multicoupler	1.29	2.58	4.30

Note 1: Assumption A - broadband antenna cost is 30K each; for B and C it is 60K and 100K respectively.

Note 2: Multicoupler cost is 140K for each 4-unit set for each frequency range.

Note 3: Cost of each base tuner, Moderate-Q or tuned whip is 30K.

Note 4: Ground system cost not included.

However, that does not satisfy the requirement for reduced land area. If the broadband antenna cost is 60K or more, that option is no lower in cost.

The tuned-whip option has the lowest system cost if the broadband antenna cost is 30K. If it is higher, some other options are at least as low. The multicoupler system cost is highest unless the broadband antenna cost is 100K. Option 2 for the broadband antenna with base tuner is appreciably higher than the other tuned-antenna options. This results from the assumption that its tuner costs as much as both tuner and antenna for the tuned whip and Moderate-Q options. This may not be a valid assumption. In particular, the tuner for the whip antenna is expected to be more complex and have higher voltages. That could lead to cost being higher than estimated.

All of the cost figures are based on estimates that require extrapolation or that are based on engineering judgement. The primary purpose in presenting these estimates is to show relative cost of the options. Considering the risk involved in making the estimates, it is concluded that cost may be roughly the same for the three tuned-antenna options. In that case other factors may be more important in making choices as to the best approach. More firm cost data are needed for guidance.

3.3 ESTIMATED DEVELOPMENT COST

Development cost for the tunable multicouplers is expected to be much higher than that for the other options. Changes from the existing designs are required to reduce insertion loss, to modify the combining circuits, and to eliminate water cooling. In addition, a new frequency range is required for 6-18 MHz. The need for three frequency ranges essentially triples the cost as compared to the antenna tuners. The circuitry is more complex and requires more components as compared to the tuners. Finally, the number of circuits required for evaluation is much greater. It is reasonable to procure two complete sets for evaluation. Since each set for each frequency range must have four channels, the total number of circuits to be constructed is 24 (3 frequency ranges times 4 channels times 2 sets). The number of tuners of each type required for evaluation may be two. This leads to a major difference in construction cost for the multicoupler option as compared to the tuner options.

A very rough estimate of development cost of the 4 options was made in order to establish probable differences. Table 3-4 shows the results.

Table 3-4. Tentative Development Cost Estimates

OPTION	ANTENNA TYPE	COST - THOUSANDS
1	Broadband with 4-unit multicoupler -	
	9 man years @ 80K	720
	6 couplers @ 300K	1800
	TOTAL	2520
2	Broadband 6-30 MHz with base tuner -	
	3 man years @ 80K	240
	2 tuners @ 60K	120
	1 antenna @ 30K	30
	TOTAL	390
3	Moderate-Q for 2-4 and 4-8 MHz; broadband for 8-30 MHz -	
	2 man years @ 80K	160
	4 Mod-Q @ 50K	200
	TOTAL	360
4	Tuned whip for 2-6 MHz; broadband for 6-30 MHz -	
	4 man years @ 80K	320
	2 tuners @ 80K	160
	TOTAL	480

This indicates roughly comparable cost for the three tunable antenna options, but the multicoupler cost may be as much as six times higher than the others. The multicoupler cost can be cut substantially by procuring only one set for each frequency range. In that case the environmental tests should be such as to preclude major damage. Otherwise the equipments may not be usable for independent Government tests and for use as models in the preproduction/ production phase.

3.4 DEVELOPMENT RISK

The multicoupler is expected to have the greatest development risk, although this is not expected to be serious. One of the risk areas is that of lowering the insertion loss as compared to that of the AN/SRA-35 series. The goal is to cut this in half. There may be problems of achieving the required increase in coupling to the antenna without causing too much tuning interaction between channels. A second potential problem area is that of achieving good temperature stability when using forced-air cooling. The AN/SRA-35 series uses water cooling through the tuning inductors, which generate the most heat. The third area relates the control of the coupling between the two resonators of each channel of the multicouplers. This coupling is a factory adjustment and the design must be such that a straightforward method can be found for setting this coupling.

The tuned whip is expected to have the next-greatest risk. The antenna reactance is much higher than for the Moderate-Q and the inverted cone (broadband above 6 MHz). The base voltage is expected to be about 26 kV rms at the peak 10 kW excursion. This is much higher than expected for the other two options. The tuning complexity is greater for this option and achievement of a simple tuning procedure is more questionable. At 2 MHz the operating Q may be at least 50 percent higher than for the other two options. This leads to a greater requirement for cooling to maintain tuning stability.

The least risk is associated with the Moderate-Q antennas. Models of these have demonstrated the capability to handle 40 kW PEP. The development requirement is primarily aimed at mechanical and reliability design. Only one tuning control is needed, so successful operability has already been demonstrated.

Risk for the inverted-cone tuner is almost as low as for the Moderate-Q. The low antenna impedance allows high efficiency and stability as one design option. However, tuning may not be as simple as for the Moderate-Q. Another design option may provide simplified tuning/switching at the expense of higher Q and higher voltage. If Q can be increased without undue problems of stability, this approach can provide more selectivity and allow smaller frequency separation between channels.

In summary, the development risks are not very high and most probably are acceptable where real performance gains can be expected. This performance gain is mostly in the area of reduced real-estate requirements and/or the ability to expand circuit requirements within a constricted area.

3.5 DEVELOPMENT TIME

The shortest development time is expected for the Moderate-Q antennas, since the electrical design is essentially complete. The next in line is the inverted-cone tuner. The lower antenna impedance allows more design freedom and more possibility of achieving a simple tuning method. The tuned whip may require appreciably more time than the inverted-cone tuner because of the greater complexity and greater cooling problem. Corona and arcing may also present some design difficulty. Development of the multicouplers is expected to require considerably more time than for the other three options. Much more construction is required and much more testing is needed to verify design decisions. It is expected to require an additional year beyond the time needed for the inverted-cone tuner or the tuned whip.

3.6 FIXED-TUNED MULTICOUPLER (HP/LP FILTER)

Equipments are now available for handling two to four circuits on one broadband antenna using high-pass, low-pass (HP/LP) filters. These equipments were not part of the development effort that is the primary subject of this report. However, some treatment of these equipments is in order to show the potential for meeting some of the design objectives that form a basis for the developments.

The HP/LP filters are available for use with 10 kW PEP transmitters. Some models will handle 40 kW PEP. Each filter allows the use of two transmitters - one above and one below a crossover band. This crossover band of some 20 percent width (i.e., 9 to 11 MHz) cannot be used. Three filters can be used in tandem to serve four circuits. However, flexibility is decreased because of three crossover bands. The most likely use of this type of multicoupler is to serve two transmitters per antenna. Most of this discussion pertains to this 2-channel application.

Cost of the 10 kW model is estimated to be 17K in 1984. This is much less than the 70K estimated for a 2-channel (diplexed) tunable multicoupler. Since these filters are now available, no development cost is involved. No

tuning is required by operators, so frequency changes can be made rapidly within the subbands. Of course the operator must switch to another port (on another antenna) if the new frequency is not in the original coverage subband.

This multicoupler is best suited to use at existing stations where expanded capability is needed or where some antennas need to be replaced because of maintenance problems. An example is presented here to indicate possible cost savings resulting from its use as compared to other means of achieving the objective. It is assumed that 12 new circuits are required. Twelve HP/LP filters are required to be installed on 12 existing antennas. Acquisition cost is 205K. If the tunable multicouplers are used, 4 are required for a cost of 560K. No change in the antenna field is required in either case.

Now consider the use of the tuned-whip antenna. Further, assume that all of the circuits are below 8 MHz. Twelve whips are required for an estimated cost of 360K. Space must be provided for these antennas and coaxial and control cables must be installed. The cost estimate of 30K per antenna included cost of the cables and installation. However, this cost estimate may be too low. Cost would be greater if some new circuits were above 8 MHz and could not be covered by existing antennas.

There is no development cost for the HP/LP filters and there is no time delay for development. It is expected that maintenance cost would be considerably less than for either the tunable multicouplers or the tuned whips. Insertion loss is much less in the HF/LP filters, and training requirements are negligible.

Some of the advantages of the HP/LP filter as compared to the tunable multicoupler are as follows:

a. No tuning required

b. Can handle 40 kW

c. Essentially no insertion loss

d. No development cost

e. Available now

f. Suited to small changes - can add 1 circuit at a time

g. No training required

h. Less maintenance

i. No air-conditioning requirement

j. No technical risk.

Some of the advantages of the tunable multicoupler as compared to the HP/LP filter are:

a. More suited to variable-frequency circuits such as for full-period ship/shore/ship

b. More flexible in general

c. Fewer constraints on frequency assignments

d. More suited to use on directional or high-angle antennas for ship/shore/ship or ground/air (HP/LP filters are not as flexible in frequency assignments).

4.0 APPLICATIONS

This section of the report examines some of the potential applications of the tunable antennas and multicouplers. One class of application relates to the shore facility status, such as new station with increased requirements, an existing station with decreased land area, or with antennas with poor maintainability. Another class of application relates to the type of circuit usage, such as fixed frequency, variable-frequency ship/shore/ship, high-angle antennas, and directive antennas.

4.1 CIRCUIT USAGE

There are many circuits that tend to remain on one frequency for long periods of time. The prime examples are the broadcasts which may stay on the same frequency for years. Another example is the shore control circuits for the Primary Ship/Shore Network. At each station acting as a shore entry point, several transmit frequencies are used and these remain fixed. There are other examples. In general, the majority of circuits fall in the "fixed" category.

The non-changing nature of these circuits essentially eliminates the need for short-term frequency flexibility. Any of the four main design options treated herein can be used without regard to flexibility. Other factors such as cost, maintainability, available land area, available building space and air-conditoning, and frequency stability become the main issues.

The variable-frequency circuits require flexibility in terms of frequency assignments. This stresses the need for minimum restrictions on the ability to select and change frequencies in accordance with Navy assignments and changing propagation. Futhermore, the time required for change and the possibility for error become prime issues. All of the issues listed for the fixed-frequency circuits also apply.

4.2 EXISTING STATIONS

Development of the various technical approaches was primarily based on reducing the land area for a given set of requirements. As such the relative merits of the options are most applicable to a new station. The existing antenna fields are generally large and not subject to major changes. These constraints may result in some modifications as to the relative merits of the options. Some of these issues are discussed here.

First consider the case of adding a requirement for more fixed-frequency circuits, and assume that no more space is available. The use of multi-couplers is indicated, since it would be necessary to remove some existing antennas in order to install the tunable antennas. It is probable that removal of antennas and installation of tunable antennas would cost more than any difference between the acquisition cost of tunable multicouplers and that for tunable antennas. The best solution probably would be to use HP/LP filters as discussed in par. 3.6, since their cost is about half that of the tunable multicouplers. If several antennas must be removed to reduce the area and still meet the existing requirements, the conclusion is the same.

Now consider the case of removing some large broadband antennas because of maintenance problems. Assume that only fixed-frequency circuits are involved, and that 12 antennas must be removed. Futhermore, assume that 6 circuits are below 6 MHz and 6 are above 6 MHz. The cost of the various options is as follows: (a) tuned multicoupler - 560K; (b) HF/LP filter - 204K; (c) tuned whip - 360K; (d) inverted cone - 540K; and (e) Mod-Q - 360K.

These estimates definitely favor the HP/LP filter. Next lower in cost are the tuned whip and Moderate-Q. The tuned multicoupler and inverted cone tuner have the highest cost.

The above conclusions are roughly the same if variable-frequency circuits are involved. This is so if these circuits require omnidirectional antennas and that the fixed-frequency circuits predominate. In that case the HP/LP filters can be used for these fixed-frequency circuits to relieve broadband antennas for the new variable-frequency circuits.

One situation may represent the most valid reason for choosing the tunable multicouplers. Most shore stations have a few high-angle and/or directive antennas. These are primarily used on the variable-frequency ship/shore/ship circuits. For that service flexibility in frequency choice becomes a prime requirement. The ability of the multicoupler to tune to any frequency in its band and to allow close spacing between adjacent channels makes it preferable to the HP/LP filter. The filter is not flexible enough to adequately cover this requirement. The tunable antennas are not designed to meet either the high-angle or the directive need.

The use of tunable antennas at existing stations is not clearly indicated. One case that could be made is to assume that most or all of the large broadband antennas are to be removed over the long term. In that case the low-frequency (2-6 MHz) requirements would have to be covered by the tunable antennas. The inverted cone with tuner would be the best choice for variable-frequency circuits, as one antenna will cover 2-30 MHz. Use of the tuned whip also requires a broadband antenna for coverage above 8 MHz. The Moderate-Q requires two (2-4 and 4-8 MHz) plus a broadband antenna above 8 MHz. Fixed-frequency circuits below 8 MHz could be covered by any of the three tuned antennas. The choice would be governed by eventual cost, operability and maintainability.

4.3 NEW STATIONS

The results presented in paragraphs 3.1 - 3.3 are generally applicable to a medium-sized or large new station. There may be more likelyhood of need for a smaller new station. For that reason some additional computations were made for that case. The following circuit requirements were assumed:

4 2-30 MHz variable frequency

3 3-5 MHz fixed frequency

3 7-9 MHz fixed frequency

3 11-13 MHz fixed frequency

3 16-20 MHz fixed frequency

These requirements are based on the assumption that four full-period ship/shore/ship circuits are required. In addition, there are two broadcasts and one Primary ship/shore net. Each of these three types requires one fixed frequency in each of the four subbands listed above.

The assumptions regarding estimated cost and spacing between antennas were the same as discussed in paragraphs 3.1 - 3.3. Table 4-1 summarizes the area and cost estimates for five options. Also included is the relative merit factors of these options, with Option 1 serving as a base.

Table 4-1. Small New Station Summary

OPTION	REQUIRED AREA-ACRES	COST $000	MERIT FACTOR
Inverted Cone - Base and Tuner	5.8	690	1.00
Tuned Whip - #1	7.7	600	0.87
Moderate-Q - #2	12.8	810	0.39
Tunable Multicouler - #3	7.7	1160	0.45
HP/LP Filter plus Inverted Cone Tuner - #4	5.8	640	1.07

Note 1: The inverted cone, tuned whip and Moderate-Q options use 6-30 MHz broadband antennas w/o multicoupling for 6-30 MHz requirements.

Note 2: Area does not include ground system or other fringe area requirements.

Note 3: Merit factor is based on Option 1 being unity.
Comparative merit of other is obtained by the following:

$$100 \times \frac{\text{base area}}{\text{area \#1}} \times \frac{\text{base cost}}{\text{cost \#1}}$$

Note 4: Cost of broadband 6-30 MHz antenna is 30K each.

The results show only a small difference between the inverted cone with tuner and the tuned whip. Option 4 is a mix of the inverted cone with tuner and the HF/LP filter for fixed frequencies above 6 MHz. This also shows only a small difference in merit. The Moderate-Q and the multicoupler options are much poorer and do not appear to be good candidates for the assumed requirements unless relative cost is found to depart considerably from that assumed here. The added frequency constraints imposed by te HP/LP filter make it questionable unless the cost advantage is found to be greater.

Cost of the 6-30 MHz broadband antennas was assumed to be 30K each in Table 4-1. Another estimate was made assuming that this may be as high as 60K. The higher value leads to system cost estimates as follows: (a) inverted cone and tuner 1170K; (b) tuned whip - 990K; (c) Moderate-Q - 1200K; (d) multicoupler - 1370K; and (e) HP/LP filter and inverted cone with tuner - 1000K. This higher estimate does not change the relative merit very much except that the multicoupler is more competitive. These results are consistent with those shown in paragraphs 3.1 and 3.2 for a larger station.

5.0 RELATIVE MERITS

The above discussion relates primarily to system cost and area requirements. Some other characteristics are included in order to emphasize certain points, but there are other factors to be considered in specific applications. This section outlines some of these factors for the four development options and for the existing HP/LP filter. These factors are presented as the advantages and disadvantages of each.

5.1 INVERTED CONE AND TUNER

The relative merits of the 6-30 MHz inverted cone ith 2-6 MHz tuner are as follows:

Advantages

a. Fewest high-voltage problems except for Moderate-Q and HP/LP filter.

b. Simplest circuit design except for Moderate-Q and HP/LP filter.

c. Simplest tuning procedure except for Moderate-Q (HP/LP filter requires no tuning).

d. Fewest model types except for tuned whip.

e. Readily adaptable to new station.

f. Adaptable to changing requirements for frequency distribution.

g. Requires fewest ground systems, transmission lines and antennas except for multicoupler or HP/LP filter.

h. Minimal inside space requirements.

i. May not require high-voltage switching.

j. Requires no antenna patching for ship/shore/ship circuits.

Disadvantages

a. Requires broadband antennas for all circuits, thus increasing antenna maintenance.

b. May be more costly than tuned whip.

c. Requires control cables and tuners.

d. Not readily adaptable to existing stations.

e. Tuner subject to outside weather.

f. Not adaptable to directive or high-angle circuits.

5.2 TUNED WHIP

The relative merits of the 2-8 MHz tuned whip are as follows:

Advantages

a. May be lowest cost option for new station.

b. Simplest installation except for HP/LP filter.

c. May be least antenna maintenance among the three tuned-antenna options.

d. Minimal inside space requirements.

e. Readily adaptable to new stations.

f. Fewest model types except for inverted cone with tuner.

Disadvantages

a. Highest voltages in tuner.

b. Requires control cables to tuners.

c. Not readily adaptable to existing stations.

d. Tuner subject to outside weather.

e. Requires high-voltage switching.

f. May require moving contacts on inductor.

g. Not adaptable to directive or high-angle circuits.

h. May have worst stability problems.

i. Requires some antenna patching for ship/shore/ship circuits.

5.3 MODERATE-Q

The relative merits of the 2-4 and 4-8 MHz Moderate-Q antennas are as follows:

Advantages

a. Proven design.

b. Shortest development time.

c. Can handle 40 kW.

d. No high-voltage problems.

e. Probably least maintenance on electrical parts.

f. Simplest tuning procedure except for the inverted cone with tuner.

g. Readily adaptable to new station.

h. Simplest circuit design.

i. Minimal inside space requirements.

j. Requires no high-voltage switching.

Disadvantages

a. Requires the most antennas because of its more limited frequency range.

b. Requires control cables to tuners.

c. Tuner subject to outside weather.

d. Not readily adaptable to existing stations.

e. Not as adaptable to changes in frequency distribution.

f. Not adaptable to directive or high-angle circuits.

g. Requires the most antenna patching for ship/shore/ship circuits.

5.4 TUNABLE MULTICOUPLER

The relative merits of the 2-6, 6-18 and 10-30 MHz multicouplers are as follows:

Advantages

a. Adapted to expansion of existing facilities w/o changes in antennas.

b. Adapted to area reduction or elimination of antennas due to maintenannce problems.

c. All complex hardware is inside for ease of repair.

d. Reduces the number of antennas to be maintained.

e. May be lower cost for changes in existing facilities as compared to tuned antennas.

f. Adaptable to directive and high-angle circuits.

Disadvantages

a. More complex hardware.

b. Greater development cost and complexity.

c. Longer lead time.

d. Requires more air-conditioning.

e. Requires much more inside space.

f. More costly stocking of equipments and spares.

g. May require increasing voltage capability on some antennas.

h. Much less efficient than the HP/LP filter.

i. Requires the largest antennas except for the HP/LP filter.

j. More complex tuning procedure.

k. Requires the most antenna patching for ship/shore/ship circuits.

l. May require the most maintenance.

m. Requires the most training.

5.5 HP/LP FILTER

The relative merits of the HP/LP filter as compared to the tunable multicoupler were listed in par. 3.6. Most of these are also listed here as being applicable to the wider comparison with tuned antennas. These are:

Advantages

a. No tuning required.

b. Can handle 40 kW as an option.

c. Esstentially no insertion loss.

d. No development cost.

e. Available now.

f. Adapted to changes in existing facilities.

g. No training required.

h. Less maintenance.

i. All complex hardware is inside for ease of repair.

j. Reduces the number of antennas to be maintained.

k. Lowest cost for changes to existing facilities.

l. No air-conditioning requirement.

m. No technical risk.

Disadvantages

a. Not well adapted to use on ship/shore/ship (full-period) circuits.

b. Less flexible for changes in frequency assignments.

c. Not well adapted to use on directive and high-angle circuits (flexibility problems).

d. Not adapted to minimizing land area requirements, particularly for new stations.

e. May require more spare units to allow for possible frequency changes (contingency).

5.6 COMPARISON SUMMARY

The foregoing merit comparisons are summarized here in order to make some tentative judgements as to expected application of each option. First, it appears that the tunable antenna options (inverted cone with tuner, tuned whip and Moderate-Q) are not the best solutions for changes in existing stations. The tunable multicoupler and the HP/LP filter are the best solutions. Of the two, the HP/LP filter is the better for general application because of its lower cost, simplier installation, minimal operating and maintenance problems, and other factors listed in par. 3.6. Lack of development cost is a prime consideration. The main use for the tunable multicoupler at existing stations is expected to be for application on directive and high-angle antennas. This may justify the high development cost.

The tunable antennas are best suited for use at new stations where the required land area is to be minimized. They also offer a much lower profile as compared to the tuned multicoupler and HP/LP filter options. The tunable multicoupler can be used to minimize land area, but its cost is expected to be considerably higher than that for the inverted cone with tuner or the tuned whip. Cost for the Moderate-Q option also is expected to be considerably

higher.

The two main contenders are the inverted cone and the tuned whip. More antennas are required when the tuned whip is used. The inverted cone requires fewer because each one covers the 2-30 MHz band for variable-frequency circuits. This leads to the larger area requirement of the tuned whip but at a reduced overall cost. The merit fctors shown in Table 4-1 are nearly the same. Choice between the two options may be made eventually on operability and maintainability factors. The tuned whip is expected to have a more complex tuning procedure, a greater risk of instability (tuning drift), more high-voltage problems, and (possibly) more maintenance problems. If the impact of these is less than expected, it may be the choice between the two.

Application of tuned multicouplers at new stations is expected to be limited to use on directive or high-angle circuits, as indicated above for existing station applications. If cost is appreciably less than estimated, this conclusion could change. The use of HP/LP filters is expected to be minimal. The higher system cost and somewhat reduced flexibility of the Moderate-Q makes it an unlikely candidate unless time becomes a major factor. It could be available in a shorter time.

6.0 COMPACT ANTENNA LIMITS

The main portion of this report treats the general case of shore antenna applications. It was assumed that land area was to be minimized while maintaining good efficiency even at the 2 MHz end of the 2-30 MHz band. There are cases when the efficiency or the low-frequency limit may be sacrificed in the interest of achieving even greater savings in space. This may be the case for special small installations where space is extremely limited. Rooftop installation is one example. This section of the report examines some of the possibilities for further reduction in size.

The first examples retain the 2 MHz requirement, but limit the antenna volume to a cylinder with a height of 15 feet and a radius of 7.5 feet. One possibility is to use a cylindrical antenna of intermediate thickness. An example was worked out for a 15 foot antenna with a diameter of 10 inches. Data were available from model studies for this example. The impedance at 2 MHz is expected to be 0.335 - j 970 ohms. All of the examples assume a perfect ground system and flat-earth mounting. The effects of an imperfect ground system and mounting on a building are discussed later in a qualitative sense.

The above impedance was used to compute the expected characteristics when optimally tuning the antenna with an inductor having a Q of 1000. The loss at 2 MHz is 5.9 dB and the antenna voltage is 84.3 kV at 10 kW PEP (peak rms excursion). The true peak is 1.4 times that amount. This is high enough to make it very questionable whether a practical tuner can be developed with available components. The unloaded Q is 760 and this is about 5 times as high as expected for a tuned whip 45 feet long. Dissipation is also several times as great. It may be impossible to achieve stability under these conditions. Lowering the inductor Q to reduce voltage and stability problems only leads to greater losses.

The problems of a relatively thin antenna indicate that it is necessary to go to extremes in utilizing the volume if the height limit is to be observed. One approach is to use an inverted cone of the same shape as that of the 6-30 MHz antenna used with the base tuner. An 18-30 MHz model is 14.4 feet across and 9.7 feet high. The impedance is 0.22 - j 240. Use of an optimum tuner with a Q of 1000 leads to a loss of 3.2 dB. The antenna voltage is 35.5 kV (peak rms excursion) and the unloaded Q is 520. These values are

well below those for the cylindrical antenna, but the Q is still high enough to pose major stability problems.

Now consider raising the low-frequency limit to 3 MHz. The impedance of the 18-30 MHz inverted cone is 0.5 - j 160 and the loss is 1.2 dB. The antenna voltage is 19.7 kV and the unloaded Q is 240. Both the loss and voltage are within acceptable limits, but the Q may still be high enough for concern in meeting stability requirements.

There are four possibilities for improvement to be considered. These are: (a) there will be some ground system loss resistance; (b) if the antenna is mounted on a building, a significant increase in radiation resistance can be expected; (c) if necessary, the inductor Q can be lowered to increase the loss resistance; and (4) the shape factor could be altered to provide a height of 15 feet and thus improve the base impedance. With all of these possibilities it appears feasible to design an acceptable tuned antenna to fit within the volume assumed. However, it is necessary to raise the low-frequency limit to near 3 MHz. Table 6-1 shows some of the main characteristics of the two antenna types as a function of frequency and inductor Q. At 2 MHz neither antenna has acceptable values in all three performance areas. However, the inverted cone is better in all three.

Further computations were made for the inverted cone at 3 MHz. Both voltage and loss are well within acceptable limits with an inductor Q of 1000. The unloaded Q may still be too high, and the inductor Q was lowered to 400 as a trial. This doubled the loss and the unloaded Q is still in the questionable area in regard to expected stability problems. Experimental data are needed to better determine if a Q this high can be used and still maintain tuning stability under temperature extremes.

It is probable that mounting atop a building will increase the radiation resistance enough to provide an acceptable Q value. Experiments are needed to determine probable gains from this type of mounting. When mounted on a flat earth, the Q can be lowered by using a smaller ground system. The extra losses have the same effect as adding losses by using a lower inductor Q. Less cooling is required, since the heat is dissipated in the earth. The ground system will be less costly as well.

Table 6-1. Compact Antenna Limits

2 MHz		
Inductor Q = 1000	**15 Foot Whip**	**18-30 MHz Inverted Cone**
Voltage - kV	84.3	35.5
Loss - dB	5.9	3.2
Unloaded Q	760	520
Inductor Q = 600		
Voltage - kV	69.5	30.5
Loss - dB	7.7	4.5
Unloaded Q	496	387
Inductor Q = 400		
Voltage - kV	58.5	26.5
Loss - dB	9.1	5.7
Unloaded Q	355	293
3 MHz		
Inductor Q = 1000		
Voltage - kV		19.7
Loss - dB		1.2
Unloaded Q		240
Inductor Q = 400		
Voltage - kV		16.9
Loss - dB		2.6
Unloaded Q		177

The Q can be lowered readily by using a larger volume. A 20 percent increase in each dimension will lower the unloaded Q by about 40 to 50 percent. A change in shape factor by using a 15 feet height along with the 7.5 foot radius for the inverted cone may provide enough improvement. Another possibility is to use the existing shape factor, use a 15 foot height, and allow the radius to be 11 feet. This is equivalent to using a 12-30 MHz inverted cone. In any event, it may be necessary to use a low-frequency limit of 3 MHz as the design requirement for dimensions as stated (15 foot height and 7.5 foot radius).

7.0 CONCLUSIONS

Based on the analyses presented in this report, the following tentative conclusions are drawn:

a. The required land area can be decreased by a factor of 4 to 8 as compared to existing stations using only broadband antennas.

b. The required area is nearly the same for the four main alternatives considered here: (1) broadband antenna with 4-unit multicoupler; (2) broadband 6-30 MHz antenna with 2-6 MHz base tuner; (3) Moderate-Q antenna for 2-4 and 4-8 MHz; and (4) 2-6 MHz tuned-whip antenna.

c. The expected efficiency of the four alternatives is roughly comparable, being about 80 percent.

d. The tuned antennas are best suited for use in a new station or where an unused area is to be used for expansion. However, multicouplers are generally more suited for expanding requirements at existing stations.

e. Although not a development alternative, the existing HP/LP filters are a prime candidate for expanding existing station capabilities. Cost of these equipments is much less than that for the tunable antennas or tunable multicoupler, and no development is required.

f. The tunable multicoupler is best suited for use on directional or high-angle antennas. The added flexibility is well suited for full-period shore/ship circuits that require frequent changes in frequency.

g. Of the four development alternatives, development cost is expected to be highest for the tunable multicoupler. Of the tunable antennas, the tuned-whip is expected to have the highest development cost; however, cost is roughly comparable among the three.

h. System cost for a new station is expected to be somewhat greater for the tuned multicoupler, with lowest cost expected for the tuned whip and the Moderate-Q antennas. However, the cost uncertainty is high enough to require further evaluation before firm conclusions can be made.

i. The cost for an all-broadband system (as presently used) is expected to be as low or lower than the narrowband alternatives. Its main disadvantage is the large area requirement.

j. For very restricted area, even smaller antennas may be used as compared to the foregoing alternatives. The following constraints apply in this case: (a) the low-frequency limit should be 3 MHz; (b) size should be specified as a volume, say a cylinder 15 feet high with a radius of 7.5 feet; (c) relatively thin antennas are not practical for heights approaching 15 feet; and (d) design problems of high voltage, tuning complexity, and stability set a limit on size.

8.0 RECOMMENDATIONS

a. Develop one or more tunable antennas for use as a method of reducing area requirements.

b. Consider limited use of tuned multicouplers, mainly for directional or high-ange antennas.

c. Consider the use of HP/LP filters for expanding capabilities or for reducing the number of antennas at existing stations.

d. Use the results of this report as a guide until further evaluation is obtained on cost and complexity of the several design alternatives.

9.0 REFERENCES

1. Systems Exploration, Inc., Report "Shore Compact Antenna System" dated 27 August 1983.

2. Systems Exploration, Inc., Report "Essential Performance Characteristics for Multicouplers" dated 27 February 1984.

3. Systems Exploration, Inc., Report "Essential Performance Characteristics for a 2-8 MHz Tuned-Whip Antenna" dated 30 March 1984.

4. Systems Exploration, Inc., Report "Essential Performance Characteristics for an Inverted-Cone Antenna Tuner" dated 30 April 1984.

10.0 ACRONYMNS

dB	Decibel
DECO	Development Engineering Corporation
HP/LP	High-pass/low-pass (filter)
K	$1000
kV	Kilovolts
kW	Kilowatts
MHz	Megahertz
Q	Ratio of reactance to resistance in a tuned circuit.

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